UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Research Service
Crops Research Division

# A SUMMARY REVIEW OF INVESTIGATIONS ON ALLIGATORWEED AND ITS CONTROL

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Cooperative investigations for Expanded Project for Aquatic Plant Control under an Agreement between the Agricultural Research Service, United States Department of Agriculture, and The Corps of Engineers, Department of the Army.

CR 33-60

September 1960

# A SUMMARY REVIEW OF INVESTIGATIONS ON ALLIGATORWEED AND ITS CONTROL [1]

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Since the introduction of alligatorweed, its spread throughout the southeastern United States and its detrimental effects have become well known. Various approaches to the problem and many attempts at controlling alligatorweed have not as yet yielded an entirely satisfactory solution. To expand this work, an agreement (1)[3] was entered into by the Agricultural Research Service of the U. S. Department of Agriculture and the Corps of Engineers, Department of the Army, to review existing literature and unpublished data to serve as a basis for further research on the control of alligatorweed. All information available on plant morphology, physiology, propagation, and environmental peculiarities as well as that relating to the control and eradication of alligatorweed by biological, chemical, and other means was reviewed and analyzed for this report.

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[1] Cooperative investigations under the Agreement (Req. No. 08-123-ENG-45-60C) between the Agricultural Research Service, U. S. Department of Agriculture and the Corps of Engineers, Department of the Army.

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[3] Numbers in parenthesis refer to reference material cited.

## GEOGRAPHICAL DISTRIBUTION AND IMPORTANCE

Alligatorweed, *Alternanthera philoxeroides*, was first described in 1826 according to Smith and Downs (54) who recently traced the earlier taxonomic work by various individuals. These are listed as follows: *Bucholzia philoxeroides* Mart. Nova Acta Acad. Leop. - Carol 13, pt. 2:315. 1826. *Telanthera philoxeroides* Moq. in DC. Prod. 13, pt. 1:362. 1849. Seubert in Mart. Fl. Bras. 5, pt. 1:169, pl. 51. 1875. *A. philoxeroides* (Mart.) Griseb. Abh. Geo. Wiss. Goett. 24:36. 1879. *Achyranthes philoxeroides* Standl. Journ. Washington Acad. Sci. 5:74. 1915. Covas, Darwiniana 5:355, fig. 9 A-F. 1941. These are early names for the plant now known as *Alternanthera philoxeroides*. Smith and Downs report the present distribution as: Banks of rivers and in marsh areas in Arangera, Mondair (along the banks of the Uruguay River), altitude 200-300 m, Porto Uniao; (along the banks of the Iguacu River and east of Porto Uniao), altitude 750 m.; Southeastern United States; Brazil; and Argentina.

Brown (15) reported the plant was discovered in Florida in 1894, but actual reference was not found to substantiate that date. Mohr (42) discovered the plant growing in the United States and reported his findings in 1901. He reports that it was found in September, 1897, near Mobile, Alabama, completely filling a creek. He states that the source of introduction was from West Indies and Brazil (S. Paulo, Bahiam, and Buenos Aires). Harper (30) quotes

Small as describing the plant in 1903. Standley (55) described the plant as *Achyranthes philoxeroides* (Mart.) Standley.

Other species of the genus *Alternanthera* have been described. Forskal (27) reported that *Alternanthera* species were being used in 1775 as a fodder for livestock. *Alternanthera achyrantha* R. Br. was found in southern Africa about 1910 (46), and was introduced into that area from South America during the Boer War (2). This creeping form (34) became a weed in that area (17). The only control measures reported have been the use of a smother crop, sodium chlorate, or a 0.2 percent arsenic solution (76). *A. echinata* J. E. Sm. has been reported as a weed in South Africa (43) and of India (33). Andrews (4), Singh (52), and Jochems (32) reported *A. sessilis* (L.) R. Br. as being a weed that invades waterways from the bank. *A. repens* (L.) O. Ktze. is considered a weed of Australia (44). Use of 2,4-dichlorophenoxyacetic acid [2,4-D] is ineffective on *A. repens*, and soil sterilants such as sodium chlorate and the arsenicals have shown some promise for control.

Vogt (72) studied over 1,500 herbarium specimens of *Alternanthera* in the U. S. National Herbarium. This included approximately 80 species of *Alternanthera*. He found the following geographical distribution:

| Geographic Region | Approximate Number of Species |
|---|---|
| United States of America | 6 |
| Mexico and Central America | 19 |
| West Indies | 15 |
| South America | 69 |
| Africa | 14 |
| Asia and Malaysia | 4 |
| Australia | 5 |

Engler and Prantl (24) reported *A. philoxeroides* as growing in Java in 1893, while Backer (9) indicated it was still found in that area in 1938. It was not listed as a weed in Java until 1940 (51) and it is not certain that the plant listed was *A. philoxeroides*.

*A. philoxeroides* continued to spread from its original infestation in 1894 and now occupies thousands of acres from Texas to North Carolina. Bellue (12) has reported a vigorous infestation on swampy land in Los Angeles, California. Massey (39,40) has also reported several infestations in Virginia. Wilson (75) reported 14 counties of North Carolina as being infested with the weed. Considerable work has been done in assembling the overall picture of aquatic weed control by the Corps of Engineers. A report was referred to the House Committee on Public Works in 1956 (73). The results of a large survey conducted in 1946 and 1947 showed there were approximately 13,620 acres of alligatorweed in South Carolina, 24 acres in Florida, 2,392 acres in Alabama, and 13 acres in Mississippi. Acreage figures are not available for Louisiana, Texas, and North Carolina. Hammack (28) has reported similar data probably from the same survey.

West (74), Stephens (60), Lynch *et al.* (35), and many others have reported alligatorweed as a severe weed and as one having great potential of developing into a most serious problem to many different industries. Lynch (36) pointed out that mats of water hyacinth and alligatorweed kill fresh-water fish by reducing the oxygen content of the water. The most important aspect of this kill is that the game and pan fish have a higher oxygen demand than predatory fish.

Thus the predatory fish survive, multiply, and hinder reproduction of the desirable fish. Alligatorweed causes the most damage in the emergent zones of the fresh and slightly brackish marshes. Lynch observed that decomposing mats of alligatorweed produce quantities of hydrogen sulfide, a gas which is highly toxic to fish and other aquatic organisms. He estimated in 1947 that there were 500,000 acres of Louisiana wetlands infested by alligatorweed and water hyacinth. He further estimated (37) in 1949 the value of the wildlife and fishery crops of Louisiana to be 20 million dollars for fresh-water fish, frogs, turtles, and crayfish, and 10 million dollars for fur animals most of which are threatened by alligatorweed as it readily replaces Typha, Sagittaria, Eleocharis, and other desirable wildlife food plants. The detrimental effects of alligatorweed in navigational waterways and irrigation systems are further described (20,47,77).

Alford (2,3) is one of the few persons to try to utilize the plant. Starkey of Clemson College upon the request of Alford analyzed alligatorweed and found it high in iron and had considerable dextrose sugar. He compares it favorably with silage harvested a little too green.

## BOTANICAL DESCRIPTION

Small (53) gives the following description of A. philoxeroides: Stem and branches decumbent or prostrate, stout, often fistulous,

3-15 cm. long, glabrous, except at the leaf-axils, and sometimes near the tips: leaf-blades 3-11 cm. long, acute or obtuse: sepals lanceolate, elliptic, or ovate elliptic, becoming 6 mm. long.

Penfound (45) studied the plant quite thoroughly and gives the following anatomical and morphological description: "the primary xylem of the roots is triarch and the secondary xylem is compact and constitutes about two-thirds the diameter of the root. The cortex contains no aerenchyma. The cork is relatively thin and only slightly colored. The hypocotyl region of the stem is very small and without aerenchyma. The bundles vary from 8 to 12 in number and are relatively small in cross-section. Adventitious roots are found at each node. The cortex at this point is not aerenchymous, but the hollow pith affords buoyancy for the plants. The stem increases in size until it gets above water where it is about three times as large as at the hypocotyl. There is a slight increase in the aerenchymous nature of the cortex, but the diameter increase is due mostly to the increase in size of the internal cavity.

The leaves are oblanceolate to spatulate in shape with a very distinct midvein. Under the epidermis is a layer of well developed collenchyma, then three fibro-vascular bundles found in a mass of parenchyma with no supporting tissue, and then a layer of poorly developed collenchyma.

The flowers are perfect and disposed in headlike spikes with white sepals. These petaloid sepals surround a peculiar stamen tube which bears stamens and staminodia alternately on its upper rim. A

top-shaped pistil, with a short style, completes the flower. Penfound was not able to find mature alligatorweed seed.

Penfound also observed that the roots of alligatorweed would not penetrate the soil when the plant was floating. He states that as the water subsides the roots enter the soil and the plant takes on the growth habit of other perennial terrestrial plants. The plant grows attached to the bank and then laterally out over the surface of the water. When the plant becomes detached from the bank, it will continue to grow as a free-floating mat. If the floating mat comes into contact with nonflooded soil, either by water subsiding or by floating against a bank, the plants revert to their rooted habit of growth. The plant seems to thrive either as a strictly terrestrial plant under field conditions or emergent from the mud up through as much as three feet of water. Studies have not been conducted to determine whether or not the plant can grow up through the water to reach the water surface, as can other emergent aquatics such as Typha.

Penfound (45) appears to be the only individual that has reported observations on the life history of the plant. His observations were made along Wilson Dam in Alabama. The growth was loosely attached to the banks, but frost during the winter evidently killed back the plants to the mud. First growth appeared March 17 and the shoots were approximately 15 inches long by May 1. Some of the shoots were 200 inches long by September and the band of alligatorweed had attained a maximum width of 15 feet.

Arceneaux and Hebert (5) reported that alligatorweed growing on terrestrial sites has a very extensive root system. They found

4.224 tons of roots per acre in the surface four inches of soil. The amount of roots per given area decreased from four inches on down to 16 inches. They found 7.294 tons of roots and rhizomes per acre 16 inches of soil. They do not indicate soil texture, structure or moisture content.

Hitchcock et al. (31) found that an application of sodium 1-napthalene-acetate induced seed set of alligatorweed. The seed was oval, 2 mm in length and had two wings on opposite sides. No other seed has been noted by other investigators even though alligatorweed is a prolific flowering plant.

Earle et al. (21) conducted the only work reported on the movement of herbicides within alligatorweed. They used 2,4-DC$^{14}$, a radioactive form of 2,4-D, in their studies. Their studies showed the average rate of upward travel of 2,4-DC$^{14}$ in alligatorweed was about 4.3 cm/hr and the downward rate was 4.2 cm/hr. The radioactive material traveled to the top or growing tip of each plant but downward movement was only one or two internodes. They found an accumulation of 2,4-DC$^{14}$ at the nodes. Tween 20 was used as a solvent for 2,4-D and there was greater absorption of 2,4-DC$^{14}$ into plants when it was used. However, they state there was no dependence of rate of travel in the plant on the solvent, or on the quantity of 2,4-DC$^{14}$ absorbed by the plant. There appears to be some confusion in these two statements as to whether or not solvent affected the amount of 2,4-DC$^{14}$ absorption. The same group (48) further reported that a wetting agent did affect the quantity of 2,4-D absorbed, but did not

affect the rate of travel or the distance traveled in alligatorweed. The mode of travel was through the vascular bundles and the epidermal tissue of the plant.

## CONTROL MEASURES

Before the discovery of the herbicidal properties of 2,4-D, little progress had been made with chemicals that were capable of destroying alligatorweed and water hyacinth. Considerable attention had been given to mechanical processes that would keep the channel-ways of navigable waters free from weeds. Wunderlich has been actively engaged in research in this field for many years. One of the water hyacinth destroyers devised by Wunderlich (65) was called Destructor "Kenny." The water hyacinth was lifted out of the water on an endless belt conveyor, from which they were passed between heavy power-driven rollers that crush the plants into pulp. Other methods (14,73) used included dragging the plants out onto banks by various methods such as conveyors or drag-line. Sawboats have also been used to cut through solid infestations in order to operate a spray-boat in the waterway. Hitchcock et al. (31) reported that alligatorweed chopped into two-inch lengths reinfested the original area within five months, while five-inch lengths reinfested only two-thirds of the original area. Brown and Carter (15) report regrowth from nodes cut down to as little as one-eighth inch in length and from pieces of underground storage roots one-half inch long. This would indicate that alligatorweed could be cut up too small and that probably more complete sprouting took

place in the plants chopped to two-inch lengths or smaller. While extremely effective for the temporary control of water hyacinth, such mechanical measures have been effective for only a short time. These mechanical devices (26) probably could aid the spread rather than control the spread of alligatorweed. However, when no other measures of control were available, these mechanical processes have kept navigable and other water areas useable.

Bitancourt (13) reported that a fungus seems to exert some degree of control of alligatorweed in South America. However, mycologists have been unable to isolate the organism in pure culture to test it for introduction into the United States.

Considerable work has been done in Louisiana on alligatorweed control by flaming (29). Arceneaux and Hebert (5) studied the affect of flaming on the total percent soluble solids in juice extracted from alligatorweed. Flaming of alligatorweed was done every week and every two weeks throughout a growing season. Samples of alligatorweed were taken five times during the growing season. They found a 75 percent reduction in soluble solids when alligatorweed had been flamed six to eight times in one season. More frequent flaming was no more effective and less flaming gave poorer control. Their results indicate that this starvation process of alligatorweed was quite slow. Further experiments by Arceneaux and Hebert (6) showed that an extremely heavy infestation of alligatorweed will reduce yield of sugar cane from 32.79 ton/A to 3.36 ton/A and the weight per stalk from 1.79 lb. to 0.77 lb. They report that 12 weekly

burnings reduced alligatorweed to 1.4 percent of that found in areas where soybeans had been used as a cover crop and turned under with alligatorweed. Sherwood (49) reported that cane production was reduced two to four tons per acre in moderate alligatorweed infestations. Further evidence by Arceneaux and Hebert (7) gave support to various cultural practices. They proposed planting _Melilotus indica_ (L.) All. about January 17. When _Melilotus_ matures about May 2 flame the area three times in weekly intervals, then plow and disc and plant Tifton sudan grass with _Melilotus indica_ again about October 16. This practice has resulted in a 54 percent decrease in alligatorweed roots the first year. The common practice of that area at that time was to plant soybeans in 6 foot rows as a competitive crop to alligatorweed. They recommend that soybeans should be planted in six-inch spacings and should be harvested for hay rather than plowed under as is usual. This practice gave 57 percent control of the underground portion of alligatorweed in one year.

Brown and Carter (15) concluded that mowing and burning were rather ineffective operations, because alligatorweed burned as many as 16 times in one year still had regrowth. Plowing five times or disking 16 times per year was ineffective. Seventeen cultivations per year gave fair control with only a few scattered plants remaining at the end of the year. Their best results were obtained by burning prior to cultivation.

Brown and Carter (15) also tried many potential herbicides which included: ammonium sulfamate, ammonium sulphate, ammonium thiocyanate plus tractor fuel, a sodium chlorate mixture, borax, chloropicrin,

copper chloride, copper sulphate, a dichloropropylene propane mixture, dinitro ortho phenols, ferric sulphate, ferric sulphate plus sulphuric acid, ferrous sulphate, sodium dinitro ortho cresylate, a powder of dinitro ortho cresol trichlorobutane, and several other coded and proprietary products. The most promising of these chemicals in their tests seemed to be borax, ammate, and chlorates. They also tried the following substituted phenoxy compounds: 2,4-D, 2,4,5-trichlorophenoxy acetic acid [2,4,5-T], P-chlorophenoxyacetic acid, monochloroacetic acid, 2,4-dichlorophenoxyacetamide, the sodium and ethylacetate salts of 2,4-D, 4-chloro-2-toxyacetic acid, and other 2,4-D materials under trade names and code numbers that are presently obsolete. Their preliminary results indicated that 2,4-D showed considerable promise for controlling alligatorweed in terrestrial sites.

Further experiments with 2,4-D by Brown and Holdeman (16) showed that fairly good control of alligatorweed was obtained with a 2 lb. application. This treatment prevented regrowth for 8 to 12 weeks and by then the cane was large enough to have a shading effect on alligatorweed. Applications were made on a broadcast basis post-emergent to the cane when the alligatorweed was three to eight inches tall. Regrowth following application resulted first after treatment with the amine formulation, then the sodium salt and finally the esters. Sherwood (49) reported that cane production was reduced two to four tons/A in moderate alligatorweed infestations. He later pointed out (50) that 2,4-D usage over a period of three growing seasons had relegated alligatorweed to a place of comparative

unimportance as a weed on sugarcane lands. Protection afforded from alligatorweed by the use of 2,4-D in sugarcane in Louisiana had an estimated value of five million dollars per year.

zur Burg (79) reported that even though 2,4-D easily controlled alligatorweed on land, it was unsatisfactory when the plant was growing on water. Fair control was obtained by making heavy applications of emulsifiable orthodichlorobenzene. He also reported some promise was given by an emulsifiable mixture of carbon tetrachloride and oil containing 2,4-D. Using 2,4-D dissolved in tributylphosphate with kerosene as a carrier gave complete control of alligatorweed growing in a tank (19). The alligatorweed was growing in mud and was emergent in water 0 to 7 inches deep. Low concentrations of 2,4-D were not effective. The spray solution was applied at 30 gal/A (equivalent to 24 lb/A a.i.). Surber (64) suggested a one percent solution of 2,4-D to control alligatorweed, but he did not state the gallonage per acre to be used. Arceneaux and Hebert (8) conducted experiments in sugarcane and found that a one lb/A application of 2,4-D sodium salt repeated three times per year over a period of three years gave complete elimination of alligatorweed. Observations showed only 14.9 percent of the alligatorweed remaining at the end of first year after these treatments and only 0.05 percent remaining at the end of the second year.

Hitchcock and Zimmerman (31,78) conducted quite a large number of experiments on the control of alligatorweed. Their results showed that 2,4-D amine at 8 lb/A gave good control of alligatorweed growing out over water and loosely attached to the bank. Best results were obtained when applied in September or October. The plants would break

loose from the pond periphery and then sink. Where the plants were rooted in the bottom, the submerged stems would regrow and control was not obtained. Good results were obtained by making applications during periods of low water. Applications of 8 lb/A 2,4-D on chopped alligatorweed gave as good control as when applied to normal growing stands.

They found that low pressure applications (150 psi or less) were more effective than sprays delivered at pressures above 150 psi. Helicopter applications delivering 2 gal/A of spray solution were most efficient in field scale applications. They compared various spraying systems and found that a TOC $1\frac{1}{4}$ in. boomjet delivering 75 gal/A or less was next most efficient following helicopter applications, and then a gun-type sprayer applying 150 to 200 gal/A was next most efficient.

Floating mats of alligatorweed in their tests exhibited little or no growth and could not survive more than 21 months unless its roots were anchored in soil. 2,4,5-T gave good control, but some of the better treatments took 21 months for the alligatorweed to sink. The amine of 2,4,5-T gave 99 percent control compared to 90 percent for the ester formulation in a single October treatment when evaluated seven to nine months later. Mixed stands of alligatorweed and water hyacinth were controlled by spraying in April and in June at 8 lb/A of 2,4-D amine. The plants had completely sunken by July 28 (78). Carey (18) recommended this type program but stated that follow-up treatments needed to be made in succeeding years. Such a program

should lead to a maintenance problem within a five-year period.

Baldwin and Ball (10) failed to control alligatorweed with 2,4-D treatments made three to six times per summer over a four-year period. They indicated, however, this would keep the weed on the canal banks or at the water edge and allow boat passage. They also applied ammonium sulfamate [AMS], isopropyl N-(3-chlorophenyl)carbamate [CIPC], trichloroacetic acid [TCA], 2,4,5-T, diesel oil, nitrate of soda, and crushed limestone at various rates on drained soil, but did not obtain complete elimination of alligatorweed in one season. Soil sterilants giving control on dry soil followed by some flooding were Polybor-chlorate 10 to 20 lb/100 sq. ft. (either dry or wet), Borascu, or Atlacide each at 20 to 30 lb/100 sq. ft. This is in general agreement with Wilson (75) who reported good results with Borascu at 10 tons/A. Indications were that more was required on dry land which was not flooded.

Eggler (22) worked with alligatorweed of various growth habits. One experiment was conducted in a borrow pit with 3 to 15 feet of water with alligatorweed growing out from the banks over the water. A 2-lb. application of 2,4-D was ineffective, and part of the area was retreated with a single 8-lb. application and the rest of the area was treated twice with an 8-lb. application. Both treatments gave 95 percent control, and would need to be repeated in succeeding years to control regrowth. Lighter applications failed to give sufficient control and a 10-lb. application was no more effective than the 8-lb. rate. Generally, little kill was obtained below the water line or

soil surface, which indicates poor downward translocation of 2,4-D in alligatorweed.

Martin _et al._ (38) reported discouraging results with 2,4-D. They state that erbon at 40 lb/A gave good control on dry land where flooding did not occur for two months after treatment. These investigations were conducted on a sandy soil. Polybor-chlorate, Borascu, or sodium chlorate eliminated alligatorweed when applied at two or three tons per acre. They also report that in flooded sites 2-(2,4,5-trichlorophenoxy)propionic acid [silvex] at 40 lb/A and 1-_n_-butyl-3-(3,4-dichlorophenyl)-1-methylurea [neburon] at 32 lb/A gave good results. Various herbicidal mixtures also showed promise. They include: neburon 16 lb/A + silvex 20 lb/A, TBA mixture at 6 lb/A + silvex at 20 lb/A, and the same rate of silvex with 33 lb/A of 2,2-dichloropropionic acid [dalapon].

Stephens and Seaman (59) have reported good control of alligatorweed by use of weighted emulsions of 2,4-D in quiescent water. 2,4-D is applied at rates of 6.7 to 8 lb/A with the specific gravity of the spray solution adjusted with xylene or chlorobenzene and emulsifier to slightly over 1.0.

The U. S. Fish and Wildlife Service has done considerable work on alligatorweed control. Much of the work conducted by its Branch of Wildlife Refuges has been of necessity exploratory in nature. Relatively few chemicals were available to research workers prior to 1952, but since that time many new herbicides have been discovered and developed. A large part of the work conducted on alligatorweed

over the past eight years has been done by or in cooperation with the Fish and Wildlife Service. The following portion of this report is concerned with the review of the unpublished reports of the Fish and Wildlife Service.

Experiments conducted in 1953 on the Savannah Refuge (66) showed that flooding of alligatorweed following treatment with 2,4-D at 8 lb/A gave best results. Lighter applications even when repeated three times per year were ineffective as regrowth was 100 percent the following year. The addition of a wetting agent to 2,4-D did not enhance the topkill. Maleic hydrazide [MH] applied at rates up to 20 lb/A was rather ineffective.

Considerable work was done by the personnel of the Sabine, Lacassine, and Savannah Refuges in 1954 (67). They verified the previous, 1953, work that wetting agents added to 2,4-D did not increase the topkill of alligatorweed. 2,4-D applied at 8 lb/A, as one treatment or in split treatments, was quite effective the first year. Two granular formulations of 2,4-D were also applied at 4, 8, and 12 lb/A to rooted alligatorweed. Some plots had no water standing in the area throughout the length of the test. The results were spotty and the best first year control obtained was 90 percent. There was no difference between the 15/30 or 30/60 mesh granules of 2,4-D. Silvex applied at 12 or 16 lb/A twice in one growing season did not allow regrowth by late that fall. These treatments appeared to be better than 2,4-D treatments. 3-Amino-1,2,4-triazole [amitrol] at rates up to 40 lb/A did not have a permanent affect upon alligatorweed. Dalapon at 60 lb/A applied to a floating alligatorweed mat was

found to be effective on one refuge, but was quite ineffective on rooted alligatorweed on another refuge.

Experiments with dalapon were continued in 1955, but the results were not consistently good (68). Best topkill was obtained where there was no standing water, and even then rates of 50 and 60 lb/A were required. An application of 2,3,6-trichlorobenzoic acid [2,3,6-TBA] was quite ineffective when two treatments each at 12 lb/A were made in one season, either on floating or rooted alligatorweed. Silvex at rates of 2 to 16 lb/A applied twice in one growing season gave best control of alligatorweed growing as floating mats. Single applications were insufficient and probably further retreatment would be required for control the second year. Stiles (61) reported good results with a weighted emulsion treatment of 2,4-D applied at approximately 2 lb/A to floating mats on the Hillsboro Canal.

Further experiments (69) on the comparison of 2,4-D and silvex showed that alligatorweed recovered from light rates of 2,4-D about one month sooner than from light rates of silvex. High rates of 2-(2,4,5-trichlorophenoxy)ethyl 2,2-dichloropropionate [erbon], 70 to 160 lb/A were applied on the Savannah and Sabine Refuges with considerably different results. Applications were made on alligatorweed growing in a terrestrial site on both Refuges. Results on the Savannah Refuge showed erbon to be quite ineffective, while erbon resulted in 100 percent control on the Lacassine Refuge. There was a stand reduction in these areas on the Savannah Refuge in 1957 (70),

but not complete control. Amitrol applied at 5 to 30 lb/A was ineffective in 1956 (69).

Erbon applications continued to result in various degrees of control (56,70). The addition of various amounts of dalapon did not increase the effectiveness of erbon at any of the rates tested. Dalapon, 2,2,3-trichloropropionic acid [2,2,3-TPA], erbon, silvex, amitrol, and 2,4-D were applied at various rates to alligatorweed growing in a drainage ditch. None of the treatments were still giving control the following summer with the possible exception of the 40-lb. rate of erbon.

Silvex at 40 lb/A applied in June or July to floating mats of alligatorweed had given complete control as indicated by observations the following April (56). 1-n-butyl-3-(3,4-dichlorophenyl)-1-methylurea [neburon], 3-(p-chlorophenyl)-1,1-dimethylurea [monuron], dalapon, erbon, amitrol, and several trichlorobenzoic acid materials or derivatives were not effective in controlling alligatorweed. Combinations of silvex with neburon, dalapon, or TBA; dalapon with TBA, neburon, and amitrol; neburon with TBA and amitrol; and TBA with amitrol for the most part gave better control than either chemical alone, but control was still insufficient. Stiles (62,63) reported that an ester formulation of 2,4-D applied at 3.34 lb/A to a stand of alligatorweed growing along a perimeter dike gave only a 50 percent reduction in the stand.

Steenis (57) reported that neburon pellets at 12½ lb/A were giving good control of alligatorweed in flooded sites the first year,

but were not effective the second year after treatment (58). 2,4-Dichlorophenoxyacetamide at 5 to 40 lb/A has given good initial topkill, but there has been considerable regrowth. Mixtures of silvex, 2-methyl-4-chlorophenoxyacetic acid [MCPA], or emid with amitrol have shown promise. The water in oil emulsions of 2,4-D and silvex applied at 4 to 8 lb/A were not effective on alligatorweed growing in any of the three habitats (71). Granular formulations of 2,4-D applied at 10, 20, and 40 lb/A were not effective on rooted alligatorweed regardless of the flooded or dry nature of the soil. 2,4,5-T at 20 and 40 lb/A and 1- to -1 mixture of 2,4,5-T and 2,4-D granules each at 10 and 20 lb/A were ineffective on alligatorweed growing rooted in a moist site. Free-floating or slightly attached alligatorweed was mostly dead following treatments of 218 and 436 lb/A of 2,4-D, 200 lb/A 2,4,5-T, and a 100 lb/A combination treatment of both chemicals, when applied as the granular formulation.

Ball (11) has made a considerable number of aerial treatments of various herbicides over the last few years. He has found that the isopropyl ester and the alkanolamine formulations of 2,4-D at rates from 2 to 8 lb/A have given only topkill, even when applied as many as four times during one growing season. Pelleted formulations and weighted emulsions of 2,4-D have also been ineffective when applied by airplane.

Mellinger (41) has reported inconsistent results with silvex at 2 to 16 lb/A with spring treatments completely regrown by fall.

Control of alligatorweed was quite good where three applications of 8 lb/A were applied during one growing season. The 1- to -1 mixture of 2,4-D - 2,4,5-T was not effective where applied as one treatment; however, three applications each at 8 lb/A gave 98 percent control the first year. The same control was obtained following three applications of a mixture containing one lb. silvex and three lb. dalapon ester per gal. each at 3 gal/A. He did not find emid more effective than 2,4-D. Experiments were conducted whereby the topgrowth of 2,4-D was killed back by 2 lb/A 2,4-D and then a second treatment of a weighted emulsion of 2,4-D or silvex (specific gravity 1.03) was applied at 4 to 8 lb/A. Topkill was complete, but none of the treatments resulted in eradication. Amitrol-T at rates of 1, 3, and 5 lb/A applied in two applications in August were ineffective for alligatorweed control.

## ANALYSIS OF RESEARCH TO DATE

Considerable work has been done on control of alligatorweed. Many of the results are conflicting, and good as well as poor results can be found for the same chemicals and at various ranges of rates for each. Part of the poor results can be explained by environmental conditions that hindered or altered the action of the herbicide. It also appears that results reported often were not based on experimental data but on visual observations of an effect of factors other than herbicidal. Many factors enter into the response of a plant to a certain treatment. These include chemical, formulation, rate of application, method or means of application, stage of plant growth,

date of observations, follow-up treatments, intrusion or association of other plants into the experimental area, and proper experimental design to allow concise interpretation of the results. All of the environmental factors can have and do have a decided effect upon the results. It is exceedingly difficult for one to interpret his own experimental results when all these factors are known, and it is almost impossible for another to interpret results without knowledge of many unrecorded factors and data.

It was decided to tabulate the data from a few of the more representative treatments and analyze the value of the data. This was done to allow interested individuals a more critical look at the results of various chemicals applied to date. The results have been classified by the three growth habits of alligatorweed, dry soil or field condition (table 1), emergent or rooted and followed by flooding (table 2), and free-floating or loosely attached (table 3).

## CONCLUSIONS

A review and analysis of the research reported to date on alligatorweed indicate that while much has been done, no completely satisfactory answer is available. The main difficulty may be the lack of downward translocation of herbicides in alligatorweed. Poor downward translocation was indicated whether the plant was growing on soil or in the water. It would appear that more research under controlled or semi-controlled conditions is needed to allow best interpretation

Table 1. Response of alligatorweed growing in a dry soil to various treatments.

| Chemical | Formulation | Rate lb/A | Date treatment applied | Date final observa. made 1/ | Final control (per cent) | Geographical location | Reference 2/ |
|---|---|---|---|---|---|---|---|
| 2,4-D | | 3,6,9 | 5/18 | 7/2 | 0 | Savannah, Ga. | 61 |
| 2,4-D | | 3.34 | 6/6 | | 50 | Savannah, Ga. | 62 |
| 2,4-D | water in oil emulsion | 4,8,12 | 7/9 | 10/1 | 0 | Georgia | 71 |
| 2,4-D | 30/60 mesh granule | 4,8,12 | 8/31 | 10/15 | 50,60,75 | Louisiana | 67 |
| 2,4-D | 15/30 mesh granule | 4,8,12 | 8/31 | 10/15 | 60,80,90 | Louisiana | 67 |
| 2,4-D | 20% granule | 10,20 | 7/18 | 10/1 | 0 | Georgia | 71 |
| Silvex | | 3,6,9 | 5/18 | 8/1 | 0 | Georgia | 71 |
| Silvex | water in oil emulsion | 4,8,12 | 7/9 | 10/1 | 0 | Georgia | 71 |
| Erbon | | 80 | 5/15+9/9 | 10/3 | 90 | Savannah, Ga. | 69 |
| Erbon | | 85-160 | 5/15 | 10/3 | 10-25 | Savannah, Ga. | 69 |
| Erbon | | 70-160 | 5/16 | 11/20 | 100 | Louisiana | 61 |

1/ Where not otherwise indicated date of observation is the same year as the treatment was applied.
2/ Refer to Literature Cited.

Table 1. (contd.)

| Chemical | Formulation | Rate lb/A | Date treatment applied | Date final observa. made 1/ | Final control (per cent) | Geographical location | Reference 2/ |
|---|---|---|---|---|---|---|---|
| Erbon | | 80,97,114, 165,200 | 6/12 | 10/1 | 20,30,60, 80,80 | Savannah, Ga. | 70 |
| Erbon | | 30 | 7/26/56 | 4/9/57 | 100 | Moyock, N. C. | 56 |
| Erbon | | 20,40 | 5/23/56 | 4/9/57 | 95,100 | Moyock, N. C. | 56 |
| Erbon + Dalapon | | 80 40 | 6/11 | 10/1 | 15 | Savannah, Ga. | 70 |
| Erbon + Dalapon | | 80 20 | 6/11 | 10/1 | 20 | Savannah, Ga. | 70 |
| Erbon + Dalapon | | 40 40 | 6/11 | 10/1 | 15 | Savannah, Ga. | 70 |
| Amitrol | | 2 to 40 | 7/54 | 10/54 | 10 | Savannah, Ga. | 67 |
| Urox | | 33 | 6/19/56 | 4/9/57 | 95 | Moyock, N. C. | 56 |
| Polybor-Chlorate | | 2T.,4T. | | | 100 | Georgia | 10 |
| Borascu | | 4T.,6T. | | | 100 | Georgia | 10 |
| Atlacide | | 4T. | | | 100 | Georgia | 10 |

1/ Where not otherwise indicated date of observation is the same year as the treatment was applied.
2/ Refer to Literature Cited.

Table 1. (contd.)

| Chemical | Formulation | Rate lb/A | Date treatment applied | Date final observa. made 1/ | Final control (per cent) | Geographical location | Reference 2/ |
|---|---|---|---|---|---|---|---|
| TBA | HC-1281-S | 1.5-12 | 5/27 | 10/13 | 10-60 | Louisiana | 61 |
| *Maleic hydrazide + (MH) | | 2.5,5<br>10 & 15 | | | | Georgia | 66 |
| *MH + Sinox general | | 2.5,5,10<br>-- | | | 0 | Georgia | 66 |
| *MH + Sinox general | | 15<br>-- | | | 70 | Georgia | 66 |
| *MH + 2,4-D | | 2.5,5,20<br>2 | | | 20 | Georgia | 66 |
| *MH + DNBP | | 2.5,5,20<br>6 & 12 | | | 20 | Georgia | 66 |

* Habitat unknown.
1/Where not otherwise indicated date of observation is the same year as the treatment was applied.
2/Refer to Literature Cited.

Table 2. Response of alligatorweed growing emergent (rooted but with moist or flooded soil) to various treatments.

| Chemical | Formulation | Rate lb/A | Date treatment applied | Date final observa. made 1/ | Final control (per cent) | Geographical location | Reference 2/ |
|---|---|---|---|---|---|---|---|
| MH | | 5 & 10 | | | 0 | Georgia | 66 |
| 2,4-D | | 8 | | | 95 | Louisiana | 31 |
| *2,4-D | Carboxymethyl hydroethel cellulose | saturated soln.of 2,4-D | -- | | 0 | Savannah, Ga. | 67 |
| 2,4-D | | 5,10 | 10/22/55 | 5/22/56 | 20,50 | Moyock, N. C. | 56 |
| 2,4-D | | 2 to 8 | 4 times/sea. | | 0 | Louisiana & South Carolina | 11 |
| 2,4-D | water in oil emulsion | 4,8,12 | 7/9 | 10/1 | 0 | Georgia | 71 |
| 2,4-D | 20% granule | 20,40 | 7/21 | 10/1 | 0 | Georgia | 71 |
| Silvex | | 5,10,20 | 10/22/55 | 5/22/56 | 0,0,20 | Moyock, N. C. | 56 |
| Silvex | | 2,4,8, 12,16 | 5/6 | | 50,20, 50,60,90 | Louisiana | 68 |
| Silvex | water in oil emulsion | 4,8,12 | 7/9 | 10/1 | 0 | Georgia | 71 |

* In water but not stated if floating or rooted.
1/Where not otherwise indicated date of observation is the same year as the treatment was applied.
2/Refer to Literature Cited.

Table 2. (contd.)

| Chemical | Formulation | Rate lb/A | Date treatment applied | Date final observa. made 1/ | Final control (per cent) | Geographical location | Reference 2/ |
|---|---|---|---|---|---|---|---|
| Silvex | 20% granule | 20,40 | 7/21 | 10/1 | 0 | Georgia | 71 |
| Dalapon | | 20,30,40, 50,60 | 5/13 | 5/27 | 95-100 | Louisiana | 68 |
| Dalapon | | 45,65 | 10/22/55 | 5/22/56 | 30,90 | Moyock, N. C. | 56 |
| 2,2,3 trichloropropionate | | 45,65 | 10/22/55 | 5/22/56 | 0 | Moyock, N. C. | 56 |
| Amitrol | | 5 to 30 | 5/24 | 10/1 | 0 | Savannah, Ga. | 61 |
| Amitrol | | 10,20 | 10/22/55 | 5/22/56 | 30,40 | Moyock, N. C. | 56 |
| Amitrol-T | | 1,3,5 | 8/4, 8/25 | 10/5 | 65,90,95 | Georgia | 41 |
| TBA | HC-1281-S | 1,5,3, 6,9,12 | 5/6 | | 10,10,40, 50,60 | Louisiana | 71 |

1/Where not otherwise indicated date of observation is the same year as the treatment was applied.
2/Refer to Literature Cited.

Table 3. Response of alligatorweed growing loosely attached to the ground or free floating to various treatments.

| Chemical | Formulation | Rate lb/A | Date treatment applied | Date final observa. made 1/ | Final control (per cent) | Geographical location | Reference 2/ |
|---|---|---|---|---|---|---|---|
| 2,4-D | | 8 | | | 95-100 | Louisiana | 31 |
| 2,4-D | Weighted emulsion | 6.7-8 | | | good | Florida | 59 |
| 2,4-D | Water in oil emulsion | 4,8,12 | 7/9 | 10/1 | 0 | Georgia | 71 |
| 2,4-D | 20% granule | 218,436 | 7/21 | 10/1 | 99 | Georgia | 71 |
| Silvex | | 2,4,8 12,16 | 5/2 + 8/11 | | 95,95,97, 99,99 | Louisiana | 71 |
| Silvex | | 10,22 | 6/20/56 | 4/10/57 | 70,100 | Wilmington, N. C. | 56 |
| Silvex | | 2,4,8, 12,16 | 6/7 | | 40,50,60, 80,30 | Louisiana | 71 |
| Silvex | Water in oil emulsion | 4,8,12 | 7/9 | 10/1 | 0 | Georgia | 71 |
| 2,4,5-T | 20% granule | 200 | 7/21 | 10/1 | 100 | Georgia | 71 |

1/Where not otherwise indicated date of observation is the same year as the treatment was applied.
2/Refer to Literature Cited.

Table 3. (contd.)

| Chemical | Formulation | Rate lb/A | Date treatment applied | Date final observe. made 1/ | Final control (per cent) | Geographical location | Reference 2/ |
|---|---|---|---|---|---|---|---|
| Dalapon | | 20,30,40, 50,60 | 4/20 + 8/11 | | 25,20,50, 80,80 | Louisiana | 68 |
| Dalapon | | 20,30,40, 50,60 | 4/26 | | 30,10,20, 70,70 | Louisiana | 68 |
| Dalapon | | 20,30,40, 50,60 | 6/7 | | 70,60,70, 60,40 | Louisiana | 68 |
| Dalapon | | 33 | 8/21/56 | 4/10/57 | 30 | Wilmington, N. C. | 56 |
| Dalapon | | 65 | 6/20/56 | 4/10/57 | 30 | Wilmington, N. C. | 56 |
| Dalapon | | 65 | 7/24/56 | 4/10/57 | 70 | Wilmington, N. C. | 56 |
| Dalapon | | 20,40,60, 80,100 | 4/21 + 9/3 | 10/54 | 95 | Louisiana | 67 |
| Dalapon + Silvex | | 33 11 | 8/21/56 | 4/10/57 | 30 | Wilmington, N. C. | 56 |
| Dalapon + Amitrol | | 45 8 | 6/20/56 | 4/10/57 | 30 | Wilmington, N. C. | 56 |
| Amitrol | | 10,20 | 6/20/56 | 4/10/57 | 20,50 | Wilmington, N. C. | 56 |
| Neburon Silvex | | 16 11 | 8/22/56 | 4/10/57 | 95 | Wilmington, N. C. | 56 |

1/Where not otherwise indicated date of observation is the same year as the treatment was applied.
2/Refer to Literature Cited.

Table 3. (contd.)

| Chemical | Formulation | Rate lb/A | Date treatment applied | Date final observa. made 1/ | Final control (per cent) | Geographical location | Reference 2/ |
|---|---|---|---|---|---|---|---|
| Erbon | | 30,40 | 6/20/56 | 4/10/57 | 0 | Wilmington, N. C. | 56 |
| TBA | Na Salt | 12,24 | 7/24/56 | 4/10/57 | 20,30 | Wilmington, N. C. | 56 |
| TBA | Polychloro | 12,24 | 7/24/56 | 4/10/57 | 60,70 | Wilmington, N. C. | 56 |
| TBA | HC-1281-S | 1.5,3,6, 9,12 | 5/2 + 7/24 | | 10,40,50 60,90 | Louisiana | 71 |
| TBA | HC-1281-S | 1.5,3,6, 9,12 | 6/7 | | 0-10 | Louisiana | 71 |
| Neburon | | 4,8,16, 32 | 6/20/56 | 4/10/57 | 0,20,20,90 | Wilmington, N. C. | 56 |
| Monuron | | 6 | 6/20/56 | 4/10/57 | 20 | Wilmington, N. C. | 56 |

1/ Where not otherwise indicated date of observation is the same year as the treatment was applied.
2/ Refer to Literature Cited.

of results. More adequate experimental design is needed with frequent and thorough recording of experimental methods and results.

Much of the Southeast has been sprayed for water hyacinth control since the survey of 1946-47 and some alligatorweed control has been reported. It is possible that the competition once afforded by water hyacinth has been eliminated and alligatorweed has spread; on the other hand, control measures may have reduced the stands of alligatorweed. Another survey such as that made in 1946-47 would be most informative and would be especially useful if the infestations could be mapped as type of habitat in which it is growing: (1) non-flooded terrestrial sites, (2) permanently or periodically flooded sites where the plant is rooted, (3) flooded sites either free-floating or loosely attached.

Considerable interest has been placed upon mechanical devices which could be used to destroy alligatorweed. It would appear from the literature that such devices would have to destroy the nodes of alligatorweed by crushing or some other means in order to be most successful.

Research over the period of the next four or five years should yield information that can be used to progressively eradicate alligatorweed. However, until such time as better herbicides or practices are developed, the regular use of 2,4-D, silvex, and perhaps certain soil sterilants offers the best promise of success in a control program.

ACKNOWLEDGEMENTS

The writer wishes to express his most sincere gratitude to Dr. D. E. Seaman and Mr. J. C. Stephens for making available their rather complete literature files on alligatorweed; to Mr. Paul F. Springer and Mr. John H. Steenis for obtaining and making available the many unpublished reports of the U. S. Fish and Wildlife Service concerning alligatorweed, and to those who have directly or indirectly assisted in locating literature and/or have reviewed this report.

LIST OF ABBREVIATIONS FOR CHEMICALS REFERRED TO IN THIS REPORT

| Abbreviation | Chemical Name |
|---|---|
| 2,4-D | 2,4-dichlorophenoxyacetic acid |
| 2,4,5-T | 2,4,5-trichlorophenoxyacetic acid |
| emid | 2,4-dichlorophenoxyacetamide |
| MCPA | 2-methyl-4-chlorophenoxyacetic acid |
| CIPC | isopropyl-N-(3-chlorophenyl)carbamate |
| TCA | trichloroacetic acid |
| silvex | 2-(2,4,5-trichlorophenoxy)propionic acid |
| neburon | 1-n-butyl-3-(3,4-dichlorophenyl)-1-methylurea |
| monuron | 3-(p-chlorophenyl)-1,1-dimethylurea |
| TBA | trichlorobenzoic acid |
| erbon | 2-(2,4,5-trichlorophenoxy)ethyl 2,2-dichloropropionate |
| dalapon | 2,2-dichloropropionic acid |

| Abbreviation | Chemical Name |
|---|---|
| amitrol | 3-amino-1,2,4-triazole |
| amitrol-T | amitrol + ammonium thiocyanate |
| AMS | ammonium sulfamate |

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